Independent Risk Analysis for the Straits Pipelines

Draft Final Report

July 16, 2018

Executive Summary

This Independent Risk Analysis for the Straits Pipelines was requested by Michigan Departments of Environmental Quality and Natural Resources, the Michigan Agency for Energy, and the Michigan Office of Attorney General (collectively the State) following the recommendation in the Michigan Petroleum Pipeline Task Force Report of July 2015 (https://mipetroleumpipelines.com/document/michigan-petroleum-pipeline-task-force-report).

The scope of work specifies the following elements:

II-A Identifying and analyzing the duration and magnitude of a "worst case" spill or release of oil or other products from the Straits Pipelines into the environment**.**

II-B Analyzing the likely environmental fate and transport of oil or other products released from the Straits Pipelines in a worst-case scenario.

II-C Analyzing how long it would take to contain and clean up the worst-case release.

II-D Analyzing the short and long-term public health and safety impacts.

II-E Analyzing the short and long-term ecological impacts.

II-F Analyzing potential measures to restore the affected natural resources and mitigate the ecological impacts.

II-G Estimating the amount of natural resource damages that would result from a worst-case release.

II-H Estimating the governmental costs that would be incurred as a result of a worst-case release.

II-I Estimating all other economic damages, public and private, that would result from a worst-case release.

Background:

The multi-agency Michigan Petroleum Pipeline Task Force was formed following the 2010 Enbridge Line 6B spill of over one million gallons of crude oil in the Kalamazoo River. The task force's 2015 report recommended the establishment of the Pipeline Safety Advisory Board (PSAB) and the commissioning of two studies of the Mackinac Straits portion of Enbridge, Inc.'s Line 5 pipelines (Line 5): this risk analysis and an alternatives analysis, published in November 2017 (https://mipetroleumpipelines.com/document/alternatives-analysis-final-rfp).

Michigan Technological University (Michigan Tech) was commissioned January 12, 2018, to perform the risk analysis. By January 26, all contracts and agreements were transmitted to the partners. Work began on February 1, 2018. The Principal Investigator Dr. Guy Meadows, assembled a team of 41 experts in relevant areas of engineering, hydrodynamic modeling, risk assessment, public health, ecology, social sciences, and economics. The project team comprises faculty and technical staff from seven Michigan universities, two out of state universities, and three consulting organizations; assistance was also provided by two independent contractors (former DoE and AFPM staff) and National Oceanic and Atmospheric Administration's Great Lakes Environmental Research Laboratory (GLERL). Michigan Tech staff supported the project management and data management/sharing. The full project team and each member's role are listed at the end of the Executive Summary.

Introduction:

The Straits of Mackinac hydraulically link Lakes Michigan and Huron (Figure ES1). The channel is 3.5 miles wide and has an average depth of 20 m. The combined Michigan–Huron system forms the largest lake in the world by surface area and the fourth largest by volume, containing nearly 8% of the world's surface freshwater. The Straits of Mackinac serve as a waterway for commercial shipping and are important for recreation, tourism, and fishing. The Straits fall within the 1836 treaty-ceded waters to which several tribes retain fishing rights.

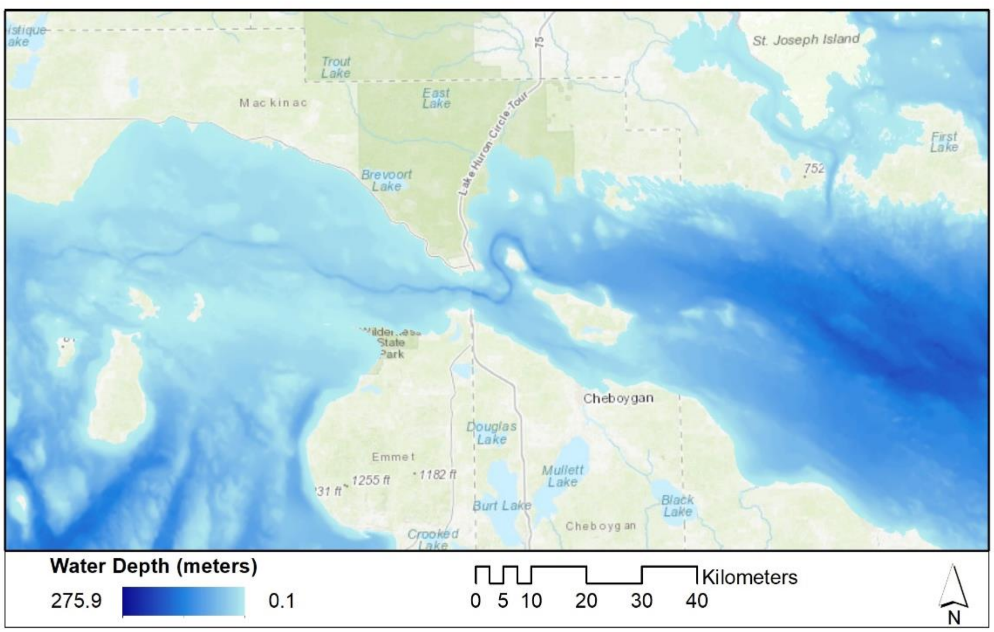

Figure ES1: Straits of Mackinac and the surrounding area. Bathymetry provided by the Great Lakes Aquatic Habitat Framework (glahf.org).

Line 5 runs for 535 miles within Michigan from Wisconsin, under the Straits of Mackinac, through the center of the state to Sarnia, Ontario. This assessment is limited to the potential impacts of spills specifically from the segment of Line 5 that crosses the Straits; it did not consider other portions of the line that are near Great Lakes shorelines, cross navigable waters, or wetlands.

No large oil spill has ever occurred in the waters of the Great Lakes. Therefore, selection of other events was reviewed to evaluate the potential impacts of a Straits spill. The July 2010 spill Line 6B is different because the product released (diluted bitumen, or dilbit) is much heavier than the products that are transported in Line 5. Furthermore, that spill did not reach the Great Lakes. Both the British Petroleum Deepwater Water Horizon and Exxon Valdez spills offer useful analogies for ecological impacts. However, marine spills do not have the risk of contaminating drinking water supplies.

The worst-case approach implemented here is based on the accumulation of worst-case assumptions, consistent with the federal definition of "the largest foreseeable discharge of oil" in 40 CFR 194.5, to yield the maximum possible volume released. This definition explicitly excludes consideration of the probability of such an event (Fidler and Wennersten 2007). As a result, this assessment extends to risks with low probabilities of occurrence but large consequences. This approach differs in aim from the "most credible major accident" scenario laid out in the Alternatives Analysis.

The impacts of a spill depend on when it occurs and how meteorological conditions disperse the oil. For example, a winter spill would be the most difficult to respond to safely and effectively (Task C); a spring spill would generate the highest economic costs (Tasks G and I); a summer spill would pose the highest risks to public health and safety due to the seasonal changes in population in the Straits area (Task D), and migrating birds would be especially vulnerable to spills during their spring and fall migrations (Task E). This variation among tasks was intended to allow the assessment to capture the worst-case damages in each of these independent and important spheres but it is important to understand that due to these seasonal differences, no single spill could cause all of the worst-case impacts described throughout this report. The spring scenario adopted by Tasks G and I is used as the representative scenario to estimate the overall liability from a worst-case scenario spill at the Straits.

Task A: Identifying and analyzing the duration and magnitude of a "worst case" spill or release.

The goal of Task A was to develop an independent estimate, grounded on the best available data and models, of the magnitude of the maximum plausible spill at the Enbridge Line 5, Straits of Mackinac crossing based on site conditions, pipeline specifications, and scenarios deemed plausible by domain experts. In particular, Task II-A of the State's Statement of Work specifies the following:

"II-A Identifying and analyzing the duration and magnitude of a "worst case" spill or release of oil or other products from the Straits Pipelines into the environment.

A worst-case scenario is understood to be a sequence of events/actions/accidents for a certain location and time that causes the worst possible magnitude of an accident. The current assessment was not required to adhere to the regulatory standards of any particular agency apart from the 40 CFR 194.5 definition of the worst case as “the largest foreseeable discharge of oil, including a discharge from fire or explosion, in adverse weather conditions”. Therefore, this assessment began from the above definition and considered a number of plausible scenarios assuming different primary causes, combined with secondary failures of various engineering and procedural controls. Prevention measure credits such as those allowable under the Pipeline and Hazardous Materials Safety Administration (PHMSA) standards were not considered, but physical processes that would limit the release and movement of released materials were taken into account.

Three previous assessments have addressed this topic: (1) the scenario developed by Enbridge to meet PHMSA regulatory requirements; (2) the memo “Defining a Worst-Case Release Scenario for the Enbridge Crude Oil Pipelines Crossing the Straits of Mackinac – Line 5”, submitted to the Pipeline Safety Advisory Board by Richard Kane in 2017 on behalf of the 501(c)3 nonprofit FLOW (For Love Of Water); and (3) the spill consequence analysis performed for the 2017 “Alternatives Analysis for the Straits Pipelines” prepared by Dynamic Risk, Inc. The assumptions made for each of these assessments and the current work are summarized in Table ES1. The Enbridge scenario was calculated to meet specific regulatory requirements rather than identify the maximum plausible spill volume. The 2017 Alternatives Analysis estimated the average consequences of a spill based on the mean shoreline oiling from 120 modeled spills for comparison with the risks of alternatives to Line 5, and so was not intended to depict a worst-case scenario.

Table ES1. Comparison of assumptions for this and previous estimates of spill volumes at the Straits.

	Enbridge Maximum Potential Release Volume	**FLOW May 2018 Straits Spill Damages Memo**	**Dynamic Risk Alternatives Analysis (2017)**	**Michigan Tech-led Independent Assessment (this report)**
Flow rate	600,000 bbl/day (Based on commercial capacity + 10%; ~3,975 m^3/hr) and assumes full design flow rate through one 20" pipeline	Not defined	1,789 m^3/hr per 20"pipeline (total 3578 m^3/hr, 540,000 bbl/day), assumes flow is split evenly between east and west lines	614,238 bbl/day (max flow rate in Enbridge-provided operational data + 5%; ~4,069 m^3/hr), assumes flow is split evenly between east and west lines

	Enbridge Maximum Potential Release Volume	FLOW May 2018 Straits Spill Damages Memo	Dynamic Risk Alternatives Analysis (2017)	Michigan Tech-led Independent Assessment (this report)
Leak size and location	Full-bore rupture of one pipeline	Rupture within the Straits crossing, detailed scenario not provided	4 scenarios: Full-bore rupture of either west or east pipeline at the bottom of shipping channel; 3" leak at either north or south end of east pipeline	Tier 1: 36 scenarios: 3" leaks and full-bore ruptures modeled at 6 critical locations along each pipeline; Tiers 2-5: 6 scenarios: double rupture at same 6 critical locations
CPM detection	Immediate	Not defined	Immediate for rupture cases; 20 min for 3" leak cases	Immediate for rupture and 5 minutes for a 3" or larger hole leak detection
Valves	Assumed to be operational	Assumes that automated and remote valve closing mechanisms fail, requiring manual closing of valves	Assumed to be operational	Tier 1: Assumed to be operational; Tier 2: Primary valves fail; Tier 3: Tiers 3 and 4: primary and secondary valves fail; Tier 5: all automated/remote valve closure fails and primary/secondary valves are manually closed
Shutdown time	Valves are remotely closed in 3 minutes	Remote valves do not work; manual valve closing occurs 2 hours after the spill begins, assumes full flow until shutdown	Valves are remotely closed in 3.5 minutes	Valves are remotely closed in 3.5 minutes except Tier 5 manual closure (2 hours)
Decision time	10 minute decision time after leak detection	Not defined	10 minute decision time after leak detection	10 minute decision time after leak detection
Drain-down	Accounts for backpressure and specific gravity differences limiting the release volume	Not defined	Accounts for backpressure and specific gravity differences limiting the release volume	Accounts for backpressure and specific gravity differences limiting the release volume

	Enbridge Maximum Potential Release Volume	FLOW May 2018 Straits Spill Damages Memo	Dynamic Risk Alternatives Analysis (2017)	Michigan Tech-led Independent Assessment (this report)
2-phase flow	Not mentioned	Not mentioned, though a 2017 memo from FLOW assumed that depressurization of NGL upstream could drive crude down the line	Not mentioned	Incorporated by assuming a minimum release of at least 15% of the crude oil remaining in the pipeline after isolation regardless of location
WCS volume(s)	6,428 bbl if valves close properly, 19,164 bbl if they do not close in the designed time frame	59,500 bbl	Approx 2,600 bbl for rupture case and 2,900-4,500 bbl for north or south shore 3" leak	Between 4,400 and 58,000 bbl

Elevation Profile and Critical Locations:

The elevation profile of the Straits crossing pipelines is shown below in Figure ES2. Six critical locations were identified: Locations 1 and 6 are the north and south ends of the Straits Pipelines, respectively, and are located at the primary safety valves on each shore. Locations 2, 3, 4, and 5 are all under water. Location 3 is at the lowest elevation point of each line (the bottom of the shipping channel).

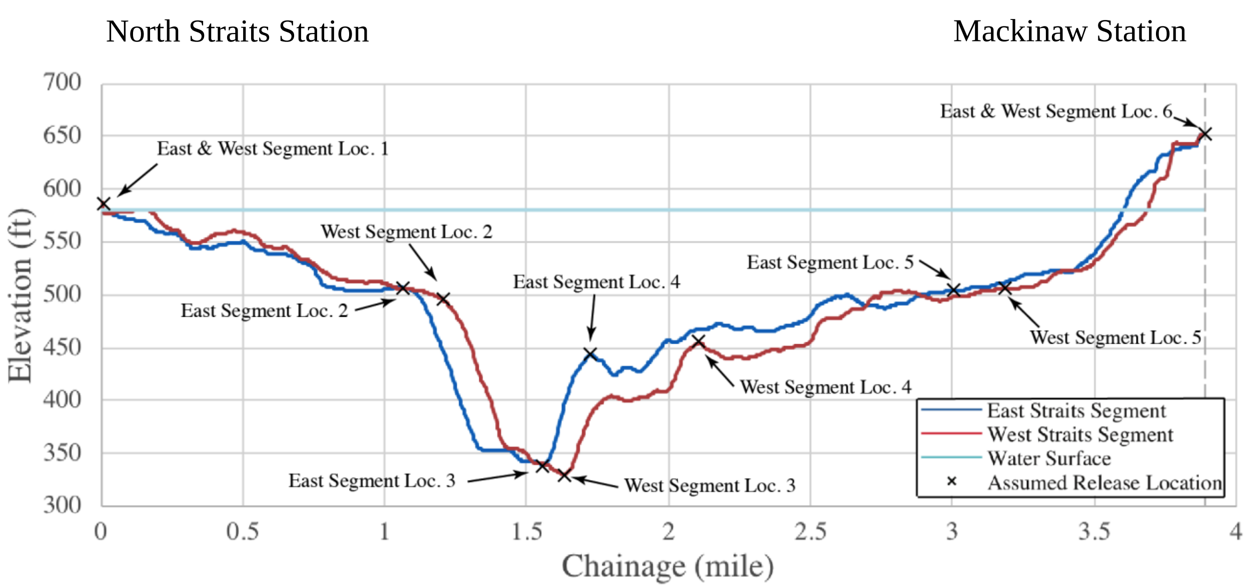

Figure ES2: Line 5 Straits crossing profiles with modeled critical locations.

Potential Causes of Failure:

The assessment considered both pinhole leak and full-bore rupture failure modes. A pinhole leak could be caused by corrosion, defects, fatigue or third-party damage. A rupture could be caused by incorrect operation, such as accidental over-pressurization or improper closing or opening of valves; spanning-related stress such as fatigue caused by vortex-induced vibration or excessive unsupported span length; or mechanical damage (including accidental damage, such as anchor drag or damage during maintenance, and malicious third-party damage).

Table ES2 summarizes the possible threats considered in this assessment and the related potential failure modes of the pipeline.

Table ES2. Primary Line 5 Threats and Associated Failure Modes.

Threats	Mode	Pipes Likely Affected
Corrosion	Pinhole leak	One 20"
Cracking (defects and fatigue)	Larger area hole	One 20"
Spanning-related stress	Guillotine rupture	One 20"
3rd Party damage	Any hole size	One or both 20"
Incorrect Operation (overpressure/hammer shock)	Guillotine rupture	One or both 20"

Tiers of Failure:

Five tiers of failure were analyzed according to the failure types.

Tier 1 – Pipeline failure in a single 20" line is identified right away, and the decision to shut down is made immediately. All equipment is working as expected. The responding time is 3.5 minutes.

Tier 2 – Pipeline failure in a single 20" line is identified right away; however, the full 10 minute decision time allowed under Enbridge protocols is utilized before valve shutdown is initiated. All equipment is working as expected. The responding time is 13.5 minutes.

Tier 3 –Pipeline failure in both lines is identified right away; both the West Strait Segment and the East Strait Segment are ruptured, and there is a failure of the primary valves. The responding time is either 3.5 min (immediate shutdown) or 13.5 min (10 min shutdown delay).

Tiers 4 & 5 – Remote electric valve closure fails, and valves have to be shut down manually. In this tier, a rupture failure at one pipe is assumed for Tier 4 and ruptures of both pipes are assumed for Tier 5. The responding time is 2 hours.

Notes:

1) If the pumps do not remain in full operation during this assumed 2-hour manual shut down time, the volume released for this tier of failure would be significantly reduced.

2) We also estimated the volume that would be released assuming a reduced time of only 1 hour to manually close only the immediate primary or secondary valves on the north side of the Straits is considered, thus interrupting the flow toward the underwater portions of Line 5. As a result, the volume estimates for Tiers 4 and 5 are presented as a range representing both shutdown timelines.

Plausibility Considerations- As noted above, to reach a Tier 4 or Tier 5 failure, multiple independent events must occur. In such a case, it is obvious that significantly less oil could be injected into the environment should reasonable actions be taken in the proper order. For that reason, we have also provided estimates of the range of spill volumes that could be realized that fall between Tier 3 and Tiers 4 & 5 failures.

Worst Case Discharge Results for Different Tiers of Failure:

Tier 1: The worst Tier 1 discharge would result from a 3" pinhole leak in the west line at Location 5 (W3Loc5) near Mackinaw Station with shutdown occurring in 3.5 minutes; the discharge amount would be 4,400 barrels of oil (bbl), containing 42 U.S. gallons per bbl.

Tier 2: The worst Tier 2 discharge would result from a 3" pinhole leak at Location 5 (either W3Loc 5 or E3Loc5 near Mackinaw Station), with shutdown occurring in 13.5 minutes; the discharge amount would be 8,600 bbl.

Tier 3: In Tier 3, both segments are ruptured at approximately the same location. The rupture discharge amounts of the West and East Segments for Location 5 are added together (ERLoc5 plus WRLoc5). If this occurs using the response time assumed for Tier 1, (3.5 minutes), based on Table A8, the estimated release is 8,300 bbl. If this occurs using the response time assumed for Tier 2 (13.5 minutes), based on Table A9, the response time is 13.5 minutes, resulting in a total discharge amount of 16,800 bbl.

Tier 4: In Tier 4, the rupture location associated with the largest release volume is at Location 5 near Mackinaw Station, and the manual shut down time is assumed to be 2 hours. During the 2 hours, the pipeline is assumed to continue carrying crude oil at the full flow rate, and all of the crude oil within this 2 hours is discharged. For one 20" pipe, the discharge amount is 25,600 bbl. After manual shutdown, the drawdown volume for location 5 on the west line is 3,400 bbl for a total discharge amount of 29,000 bbl.

Tier 5: In Tier 5, the rupture is also assumed to be at Location 5 (both ERLoc5 and WRLoc5) near Mackinaw Station, and the manual shutdown time is assumed to be 2 hours. During this 2 hours, both pipelines are still carrying crude oil at the full assumed flow rate, 25,600 bbl/h, and all of the crude oil within this 2 hours is discharged. The discharge amount is 51,200 barrels. This is added to the combined post-shutdown drawdown volume of 6,800 bbl from both 20" lines at Location 5 for a total release volume of 58,000 bbl.

Table ES3 summarizes the worst case discharge volumes for the defined five tiers of failure. These estimated volumes would apply to spills of either light crude or natural gas liquid (NGL).

Table ES3. Straits Crossing Pipeline Worst Case Discharge Volume in U.S. Oil Barrels for Different Tiers of Failure.

Tier 1 (barrels)	**Tier 2 (barrels)**	**Tier 3 (barrels)**	**Tier 4 (barrels)**	**Tier 5 (barrels)**
4,400	8,600	17,000	16,200 to 29,000	32,400 to 58,000

Task B: Analyzing the likely environmental fate and transport of oil or other products released from the Straits Pipelines in a worst-case scenario.

The goal of this task was to accurately forecast the extent of oil distribution (surface area and shoreline oiling) from a Straits spill, the timeline within which it occurs, the changes to quantity of oil as a result of evaporation, the atmospheric dispersal of the volatile components and to do so under all expected atmospheric forcing over a full year at 6 hour increments.

Task B analyzed the fate of petroleum products using hydrodynamic and Gaussian dispersion modeling. Simulations were conducted for representative meteorological, water current and ice cover conditions from January – December. The simulations generated the spread of oil on the surface, the atmospheric dispersal of volatile components, and the extents of shoreline oiling that could occur during periods up to 60 days after an oil release in the absence of clean-up and mitigation efforts.

A total of 4380 unique spill scenarios were modeled. The observed meteorological and water conditions from the year 2016 were used to generate the scenarios. The scenarios, therefore, represent a set of possible outcomes from real weather conditions. A range of weather conditions can occur in every month of the year. Therefore, the specific date of a particular simulation does not indicate that scenario likely to occur at the same time (or even season) in other years.

Modeling Framework

The computational modeling framework used to predict water current patterns and flow in the Straits of Mackinac region is based on the next-generation Lake Michigan-Huron Operational Forecast System (LMHOFS), developed by NOAA GLERL. The LMHOFS hydrodynamic model is a free-surface, hydrostatic, primitive-equation hydrodynamic model that solves the continuity, momentum, and energy equations in three-dimensions on an unstructured, sigmacoordinate (terrain-following) mesh. This approach is derived from the Finite Volume Community Ocean Model (FVCOM; Chen et al., 2006). FVCOM has been successfully validated and applied in the Great Lakes and the Straits of Mackinac (Schwab 2014, 2016). The model is available for ongoing analysis of the Straits and has advanced the state of predictive modeling for the Great Lakes.

The model was driven with 2016 meteorological data from NOAA's operational High-Resolution Rapid Refresh (HRRR) atmospheric model. The accuracy of model predictions for water currents within the Straits of Mackinac region was assessed by comparison against real-time monitoring data retrieved from Michigan Tech's Mackinac Straits West meteorological buoy (45715; http://glbuoys.glos.us/45175/) for the 2016 open water monitoring season.

Oil Dispersal Simulation

In this assessment, the dispersal of oil was simulated using a cloud of individual tracer "particles" that move with water currents. For each simulation, the oil discharge was represented by 10,000 unique tracer particles that were released from one of the three potential rupture sites. Currents and winds then drove the particles. Winter ice cover was included.

Evaporation rates were calculated for each particle as determined by the temperature profiles experienced by each particle during dispersal. The atmospheric dispersion model predicted ground-level concentrations of total volatile organic compounds (VOCs) and benzene, toluene, ethylbenzene and xylene (BTEX) compounds directly downwind from the release site.

Sample scenarios showing the greatest impacts on beaches and surface water for each modeled month are described below, condensed from the 4380 model scenarios. Although they are labeled according to the date of the weather conditions modeled, similar scenarios could happen at any time of the year.

Hydrodynamic Modeling Results - Oil beaching

Table ES4 summarizes the maximum oiled shoreline distances determined from a modeled worst-case release of oil. Most scenarios showed Lake Huron shorelines to be at the greatest risk of shoreline oiling. Lake Michigan shorelines were predicted to be most susceptible to oiling in the worst cases during three of the twelve simulations. The single greatest distance of oiled shoreline was 711 km (567 miles in Lake Michigan and 144 km in Lake Huron). Ruptures at any of the points considered could lead to extensive shoreline oiling.

Table ES4. Summary of monthly maximum shoreline oiling distances (km) predicted for the Straits of Mackinac region during 2016 meteorological conditions. These events occurred on specific dates in 2016; they could occur at any time of the year.

Release date and time	Release Location	Dispersal duration (days)	Total oiled shoreline distance (km)	Lake Michigan shoreline (km)	Lake Huron shoreline (km)
01/17/2016 1800hrs	North	60	558	38	520
02/28/2016 1200hrs	Center	60	711	567	144
03/01/2016 1800hrs	Center	60	704	558	146
04/24/2016 1800hrs	South	60	542	542	0
05/12/2016 1200hrs	Center	60	412	5	407
06/20/2016 0000hrs	Center	60	514	0	514
07/13/2016 0000hrs	North	60	427	0	427
08/21/2016 0600hrs	South	30	353	0	353
09/17/2016 0000hrs	South	20	321	1	320
10/08/2016 0000hrs	South	10	182	0	182
11/30/2016 0000hrs	South	15	314	3	311
12/27/2016 1800hrs	Center	15	225	37	188

The dates and times refer to the date of the 2016 weather conditions used for the model. Release location indicates the section of failure. Dispersal duration indicates the time in days during which FVCOM hydrodynamic model simulations predicted the maximum extent of surface area oiling for the meteorological, water current and ice-cover conditions present in the Straits of Mackinac region for the simulation month. Graphical representations of the dispersal simulations included here are provided in Figures B6-B17 provided in Appendix B of the Task B report.

Hydrodynamic modeling results - Surface oiling

Table ES5 summarizes the maximum oiled water surface areas determined from a modeled worst-case release of oil. As for the results for oiled shorelines, the majority (8 of 12) of these dispersal simulations predict that the oil spreads mainly to Lake Huron surface waters. In four of the twelve sample months, oil was entirely or almost entirely confined to Lake Michigan. Over 1000 km^2 were covered in 5 of these sample scenarios. The single greatest extent of surface area oiling (1745 km^2) was predicted to occur solely on Lake Michigan. In that simulation, oil was released from the north location on the pipeline. In general, as for the shoreline, ruptures at any of the failure points considered could lead to large areas of surface oiling. For all of the simulations, maximum oiled surface areas were predicted to occur during or within 30 days of oil release.

Table ES5. Summary of monthly maximum water surface area oilings (km^2) predicted for the Straits of Mackinac region during 2016 meteorological conditions. Although these events occurred on specific dates in 2016, they could occur at any time of the year.

Release date and time	Release location	Dispersal time (days)	Total oiled surface area (km^2)	Lake Michigan surface area (km^2)	Lake Huron surface area (km^2)
01/18/2016 1800hrs	North	15	921	1	920
02/28/2016 0000hrs	Center	15	783	757	26
03/15/2016 1800hrs	South	30	1102	1102	0
04/24/2016 1200hrs	North	30	1745	1745	0
05/12/2016 1800hrs	North	20	712	0	712
06/20/2016 0000hrs	Center	20	1033	0	1033
07/14/2016 0000hrs	Center	20	1288	0	1288
08/21/2016 0600hrs	South	15	1317	0	1317
09/17/2016 0000hrs	South	6	563	0	563
10/26/2016 0000hrs	Center	6	494	494	0
11/29/2016 1800hrs	Center	6	572	0	572
12/13/2016 1800hrs	North	6	723	0	723

The dates and times refer to the date of the 2016 weather conditions used for the model. Release location indicates the general location of oil release. Dispersal time indicates the time in days during which FVCOM hydrodynamic model simulations predicted the maximum extent of surface area oiling for the meteorological, water current and ice-cover conditions present in the Straits of Mackinac region for the simulation month. Graphical representations of the dispersal simulations included here are provided in A-B1-13 through A-B1-24 of Appendix B-1.

Hydrodynamic Modeling results - Proportional Fate

The proportion of oil that is beached, evaporates, or remains on the water surface during the 60 days after release was also determined (Task B, Figures B30 – B41). Because the vapor pressure of the volatile components depends on the temperature, in cold weather only 5-10% of the oil evaporates while in the summer up to 40% could evaporate. The volatile components evaporate within the first few days after release.

The remaining oil is gradually deposited on shorelines, typically within 60 days. The rate of deposition is highly dependent on prevailing winds and currents. Under some weather conditions, for example, the September simulation, all oil on the surface water in beached within ten days. In others, about 3% remained on the water after 60 days.

Atmospheric Dispersal Analysis - Crude Oil

A worst-case scenario for atmospheric VOCs was modeled for a plume that could reach Mackinaw City. Figure ES3 shows a contour plot of the VOC plume from just downwind from the source of the spill to Mackinaw City. These models show that populations in and around Mackinaw City would experience VOC inhalation exposures at concentrations of between near 1.0 x 10^6 – 4.1 x 10^6 μg VOC/m^3 air over an area of approximately 2 km x 1 km. Higher VOC concentrations would be present over water before the plume reaching the city, which may present a risk to any boaters or recreationists on the water at the time of release.

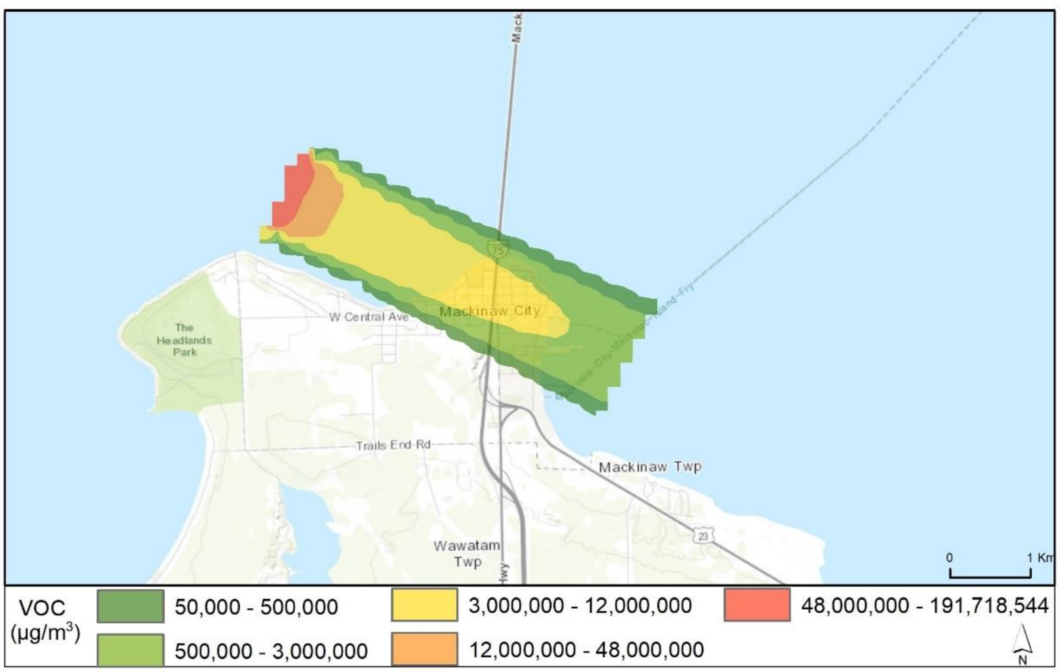

Figure ES3: GIS overlay map depicting VOC plume from Line 5 oil spill during atmospheric dispersal over Mackinac City. Colors represent VOC concentrations within the plume in units of μg/m^3.

Scenario Summary

It is not possible to define a single worst-case scenario for the dispersal of oil following release from the pipeline. For example, the worst-case situation for undertaking spill mitigation and cleanup (Task C) is a rapidly spreading release in difficult winter conditions, while a worst-case for ecosystem impacts (Tasks E) is the one that covers the most shoreline. Therefore, in order to the judge the maximum possible cost of a spill, each Task selected one of several model scenarios that corresponded to the worst case for their specific scope of work.

Table ES6 shows the characteristics of the scenarios chosen by each group and their selection criteria. A full complement of scenarios representing the maximum length of oiled shoreline and the maximum surface area of floating oil observed for each month of modeled conditions can be found in Appendix B-1.

Table ES6. Summary of the specific spill scenarios that were selected as the case studies for each task of the assessment.

Assessment Task(s)	Simulation Date	Release location[1]	Figure[2]	Rationale
C	12/27	Center (Loc. 3)	C5	Longest oiled shoreline 6 hours into spill, difficult winter conditions
D	7/25	North (Loc. 2)	D2	Largest area of floating oil 12 hours after the spill begins in July
E and F Scenario 1	4/3	Center (Loc. 3)	E2	Longest oiled shoreline in Lake Michigan after 10 days
E and F Scenario 2	2/3	North (Loc. 2)	E2	Longest oiled shoreline in Lake Huron after 10 days
E and F Scenario 3	3/12	South (Loc. 5)	E3	Longest oiled shoreline in Lake Michigan after 60 days
E and F Scenario 4	1/19	North (Loc. 2)	E3	Longest oiled shoreline in Lake Huron after 10 days
G, H and I Scenario 1	3/1	Center (Loc. 3)	GI7	Longest oiled shoreline for a March spill (a spring spill has the greatest effect on resource use)
G, H and I Scenario 2	4/24	South (Loc. 5)	GI7	Longest oiled shoreline for an April spill (a spring spill has the greatest effect on resource use)
G, H and I Scenario 3	5/12	Center (Loc. 3)	GI7	Longest oiled shoreline for a May spill (a spring spill has the greatest effect on resource use)

1. 'Release location' refers to the three locations along the pipeline modeled as spill origin sites (see Figure ES-2).
2. Figures are in sections indicated; figures showing maximum oiled shoreline distances by month are compiled in A-B1-1 through A-B1-12 in Appendix B-1.

As examples, figures ES4 through ES6 correspond to the scenarios that demonstrate maximum oiling events for selected months modeled. These correspond to a total oiled shoreline distance of 558 km following an oil release date and time of 01/17/2016, a total oiled shoreline distance of 711 km following an oil release date and time of 02/28/2016, traveling into Lake Michigan and a total oiled shoreline distance of 704 km following an oil release date of 03/01/2016 in early spring.

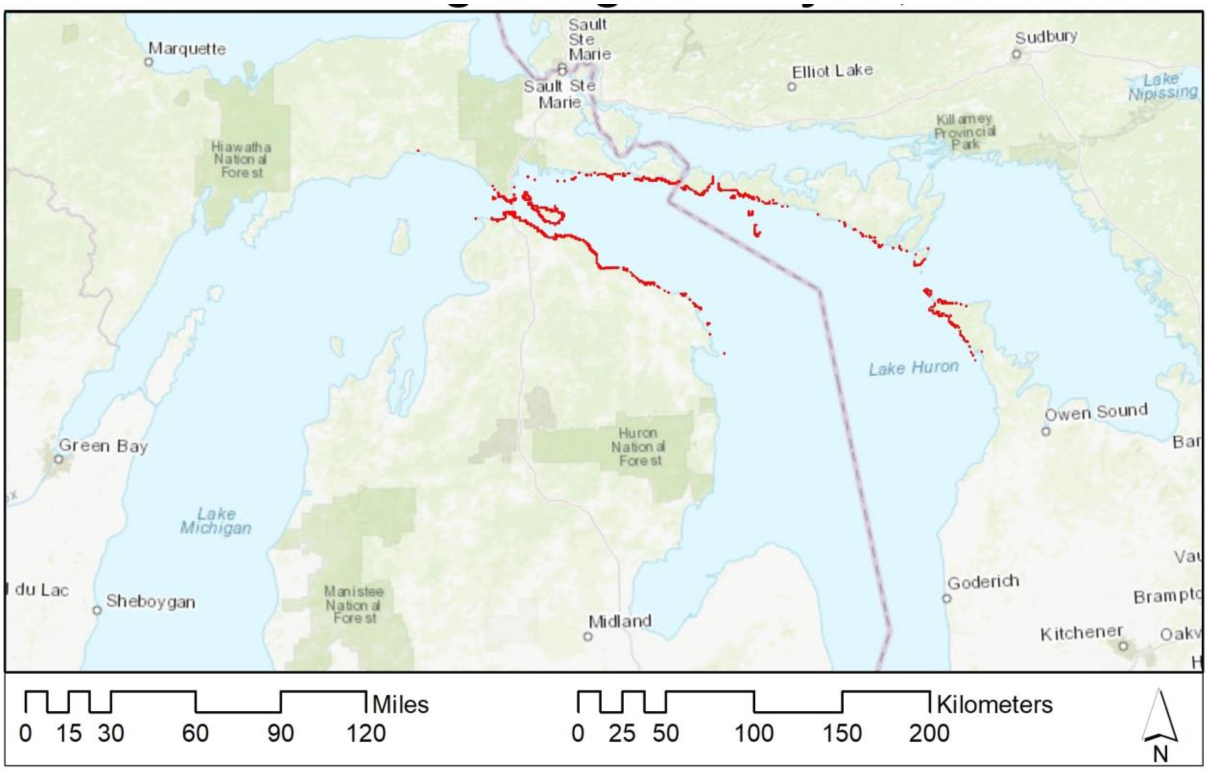

Figure ES4: The maximum extent of shoreline oiling (km) predicted for the Straits of Mackinac and adjacent Lake Michigan and Huron regions as associated with the meteorological, ice cover and water current conditions observed for January. Results depicted above represent a total oiled shoreline distance of 558 km following an oil release date and time of 01/17/2016 at 1800 hrs from the northern pipeline release point and a total dispersal simulation time of 60 days. The red particles represent dispersed oil.

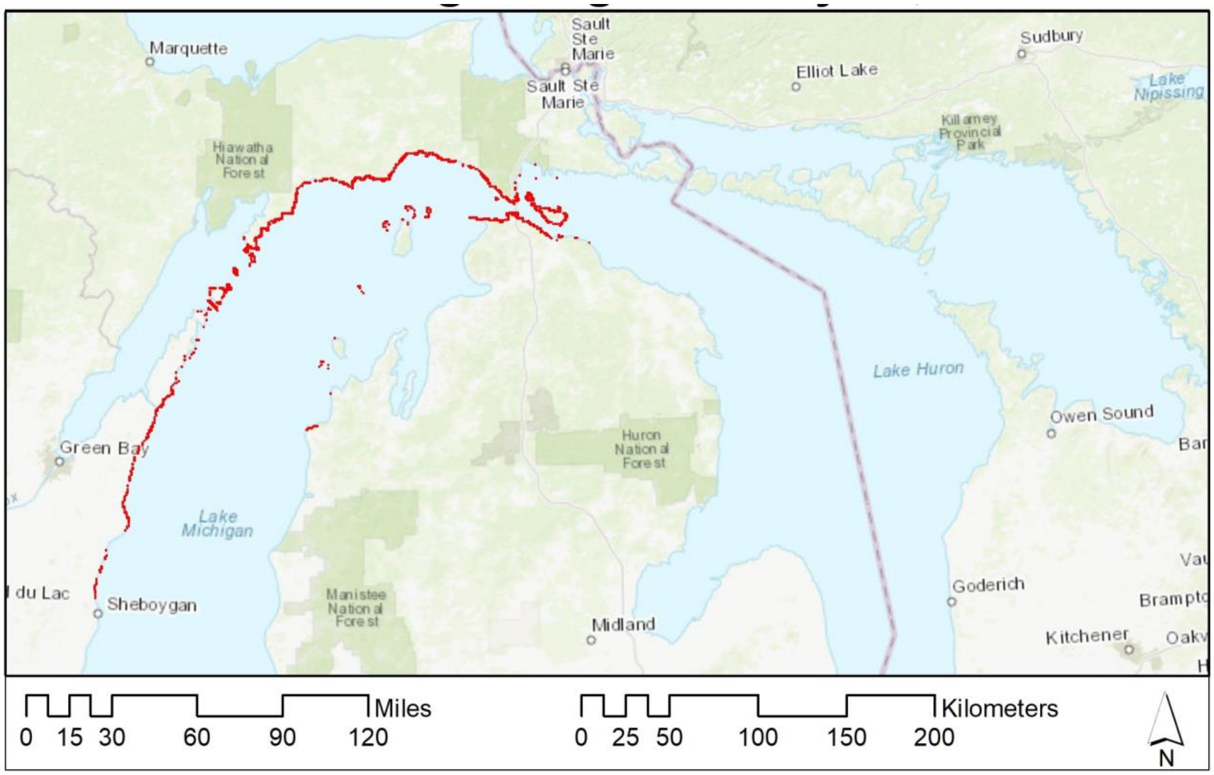

Figure ES5: The maximum extent of shoreline oiling (km) predicted for the Straits of Mackinac and adjacent Lake Michigan and Huron regions as associated with the meteorological, ice cover and water current conditions observed for February. Results depicted above represent a total oiled shoreline distance of 711 km following an oil release date and time of 02/28/2016 at 1200 hrs from the central pipeline release point and a total dispersal simulation time of 60 days. The red particles represent dispersed oil.

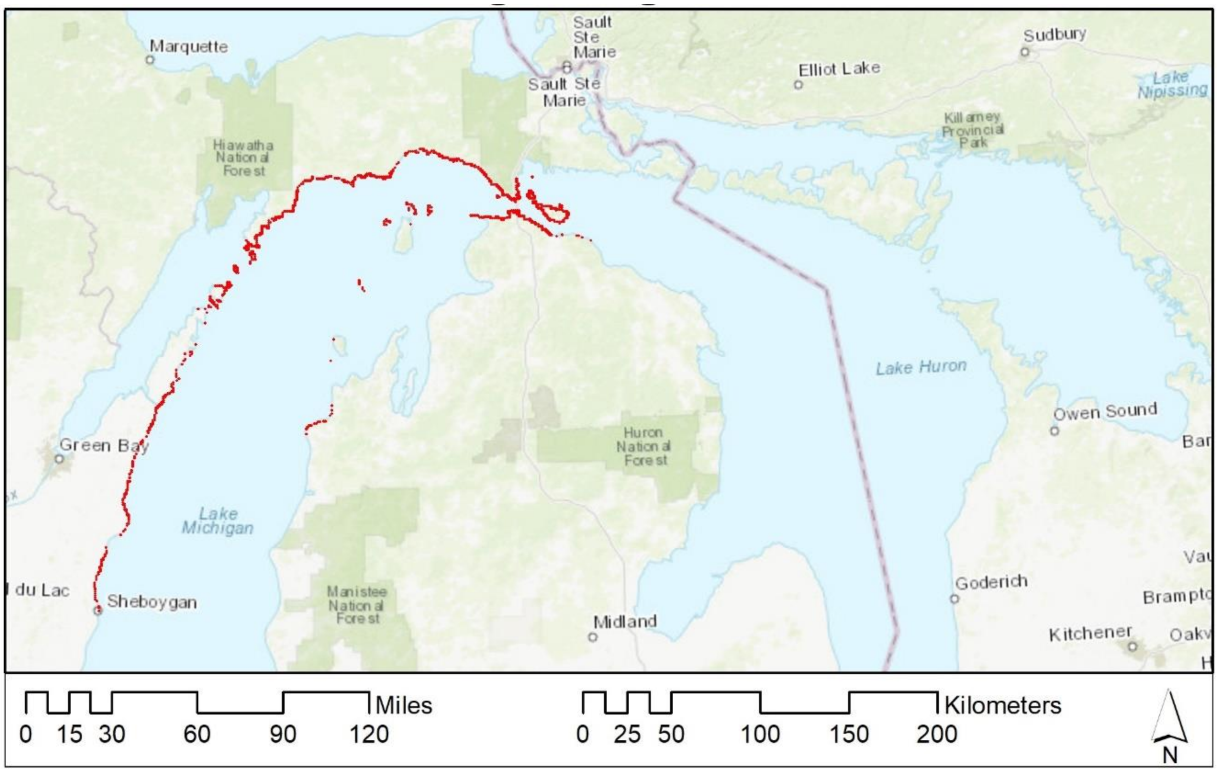

Figure ES6: The maximum extent of shoreline oiling (km) predicted for the Straits of Mackinac and adjacent Lake Michigan and Huron regions as associated with the meteorological, ice cover and water current conditions observed for March. Results depicted above represent a total oiled shoreline distance of 704 km following an oil release date and time of 03/01/2016 at 1800 hrs from the central pipeline release point and a total dispersal simulation time of 60 days. The red particles represent dispersed oil.

Task C: Analyzing how long it would take to contain and clean up the worst-case release.

Task C identified the spill containment and recovery resources available from both private and public sources to respond to a spill in the Straits. The Response Options Calculator (ROC) (NOAA Office of Response and Restoration, see: https://response.restoration.noaa.gov/oil-and-chemical-spills/oil-spills/response-tools/response-options-calculator.html) was applied to assess oil response and recovery times for the worst-case volume of oil spilled (determined by Task A) and dispersal scenarios from Task B. The fate of oil was modeled to estimate the amount of oil evaporated, recovered, and remaining on the water during the five days after release. Beaching was not calculated. Therefore the “oil remaining” fraction should be considered as distributed between the surface water and shoreline.

On Water Oil Response Strategies

Physical, chemical, and biological methods are applied to mitigate released oil. Physical methods use booms, Current Busters, and skimmers to contain and recover floating oil. Chemical dispersants are not considered as they are not permitted in the Great Lakes. In situ burning of oil on the water may be considered when conditions are favorable (and appropriate approval is granted). Biological remediation is appropriate for long-term restoration of oil-impacted shorelines.

Recovery of oil from surface water is fastest and most efficient in calm waters. Performance of booms, Current Busters, and skimmers degrades rapidly with increasing waves and becomes impossible when waves exceed approximately 1.5 meters. Recovery efficiency decreases as the oil spreads because thinner layers are more difficult to collect.

Ice cover hinders deployment of open water equipment, but ice may be beneficial because it can be used as a natural containment system and may protect the shoreline from oil. Skimmers can recover oil through holes and slots cut into the ice. In situ burning of ice-trapped oil could be feasible.

Inland Oil Response Strategies

Containment of oil near shore is accomplished by the deployment of booms around sensitive areas prevent oil from reaching the shore and diverting the oil to collection zones. Oil sorbent booms can be applied in nearshore settings to capture oil as it approaches shore or to collect oil from beaches that have already been oiled. However, the oil-soaked sorbent material must be treated as hazardous waste.

Beached oil can be washed into the water with high pressure and/or high-temperature hoses, and subsequently recovered by shallow water skimmers. Heavily oiled beach substrate may be removed and replaced with comparable material. In situ burns on shore can be used where feasible and permissible.

If full recovery of oil cannot be made or would be too damaging to the environment, biological remediation is applied. In some cases, nutrients are limiting and thus need to be applied to stimulate the biological community to break down the oil (Venosa and Zhu, 2003). The process of bioremediation often requires longer time frames (e.g., months) than other clean-up strategies (days to weeks) and is routinely monitored to ensure appropriate removal of the oil.

Fate of Oil in a Worst-Case Spill

The criterion chosen for a worst-case for response and recovery was “the longest distance of shoreline was oiled within the shortest amount of time”, which was the scenario of oil released from the center of the Straits at 6 am on December 27, 2016. No ice was present. A situation where a large extent of shoreline is oiled in a short amount of time poses the greatest challenge for recovery because clean-up of shoreline is more difficult and requires more time than on water clean-up. While the analyses for this Task C estimate how long it would take to recover and clean up oil based on this specific event with corresponding weather conditions, a similar event could happen on any date during a different year. A release of 58,000 barrels of light crude corresponds to 52,200 barrels of recoverable oil, as defined by the Code of Federal Regulations (CFR) Title 33 (CFR, 2018).

In the selected scenario, within 6 hours release, 29 km of Lake Huron shoreline would be oiled. 70 km would be oiled after 72 hours (5 days), and over 160 km would be oiled after 216 hours (10 days). Figure ES7 maps the distribution of oil in Lake Huron over five days.

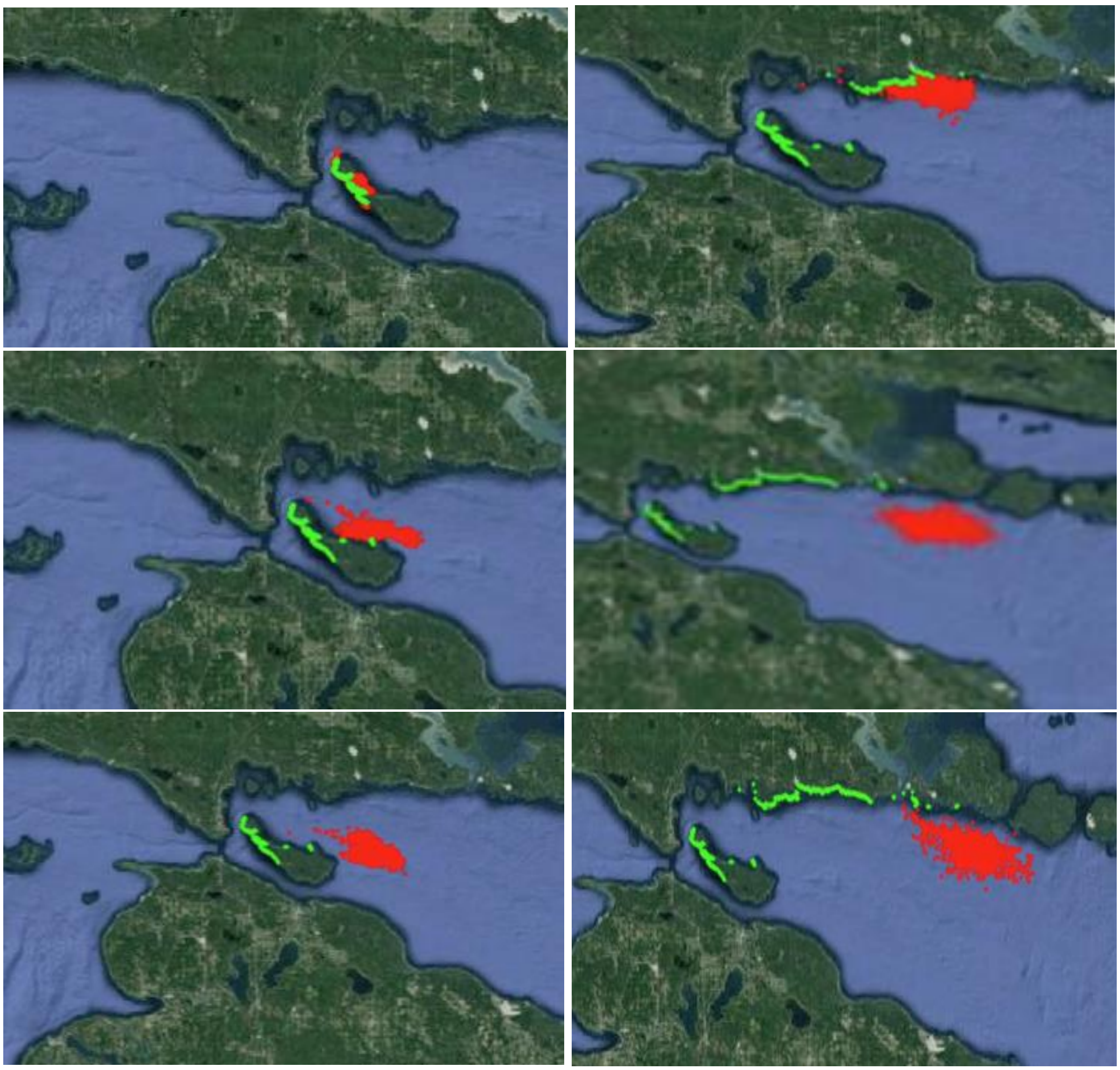

Figure ES7: Fate of oils on water (red) and shorelines (green) 3, 12, 24 (left), 48, 96, 120 (right) hrs after the oil release from the center channel of the Straits of Mackinac at 6 am on December 27, 2016. Appendix C1 provides the wave and current data for this event.

Containment and Recovery on Water

The following items are available for immediate use at each North and South side of the bridge:

- 4 × Current Buster II [90 barrels/hr (3,780 gallons/hr)];
- 4 × Current Buster IV [200 barrels/hr (8,400 gallons/hr)];
- 4 × skimmer (model TDS 150) [185 barrels/hr (7,770 gallons/hr)];
- Boom [a total of 5,000 feet can be covered] and four transport trailers;
- 2 × bucket recovery systems: one in Sheboygan and one in Escanaba.

The ROC simulation scenarios were run for five days, with a 24-hour workday. Two sets of weather conditions were considered, (1) a no-wind scenario, and (2) wind speeds up to 40 kts, as recorded by the Spectacle Reef station on the hypothetical release date. In both simulations, the equipment was assumed to be ready for deployment within 2 hours of the spill.

In the no-wind scenario, 21,077 barrels of oil (40%) could be recovered, and 6,837 barrels (13%) would remain on the water after five days. Under the poor weather conditions that occurred on Dec 27, 2016, only 1,313 barrels (2.5%) would be recovered, and 24,564 (47%) would remain on the water after five days. Wave action would also disperse 1,679 barrels (3.2%) into the water column as small droplets. In each case, the remainder evaporates (40%, no-wind; 48% with wind) (Table ES7). If in situ burning were allowed and weather permitted, 2,233 bbl of oil (4.2%) could be burned.

In the real world, oil would be both deposited on shorelines, as modeled by Task B and recovered from the water as simulated here for open water environments. Because both models could not be run simultaneously, a portion of the “oil remaining” and “recovered” fraction shown here would likely reach shorelines.

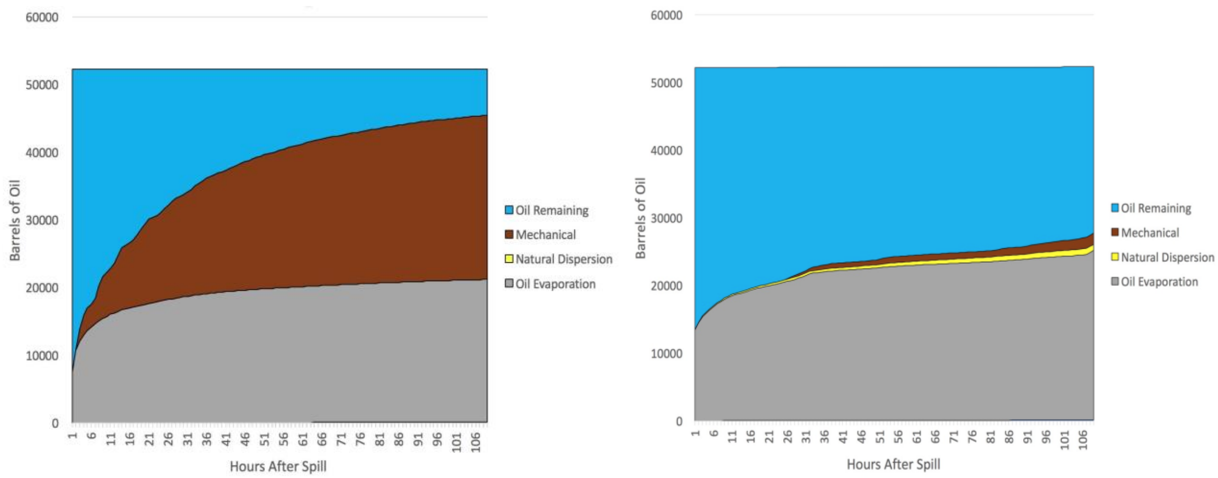

Figure ES8a: Oil recovered as a function of time from ROC simulations under 24-hour operations. No-wind scenario (left), and wind speeds up to 40 kts (right). Oil remaining is shown in blue. Oil that evaporated is shown in grey. Oil that was naturally dispersed in shown in yellow. Oil that was mechanically recovered with skimmers, booms, and current busters is shown in brown.

Table ES7. Oil recovery estimates from ROC simulations based on a 24 hour work day with and without wind conditions from Dec. 27th, 2016.

Category	**Volume of oil with no wind (bbl)**	**Volume of oil with wind (bbl)**
Evaporation	21,077 (40%)	25,066 (48%)
Mechanical Recovery	24,286 (46%)	1,313 (2.5%)
Natural Dispersion	0	1,6789 (3.2%)
Remaining on water	6,837 (13%)	24,564 (47%)

Estimated Time to Clean up Oils on Shorelines

Shoreline recovery times for three previous oil spills show that the time to achieve 90% cleanup ranges from 2 months (Refugio CA spill, 24 miles oiled) to 19 months (Deepwater Horizon, 1102 miles oiled). The Kalamazoo spill (38 miles of river shore) took 12 months to clean. Beach closure times ranged from 2 (Refugio) to 23 months (Kalamazoo); fish closures ranged from 41 days (Refugio) to 24 months (Kalamazoo).

Task D: Analyzing the short and long-term public health and safety impacts.

This report investigated the risks posed to public health and safety associated with exposure to crude oil or NGL products and their constituents following a potential rupture and release of these materials from the submerged Line 5 pipeline that transits the Straits of Mackinac. The risks posed to potentially exposed populations are primarily dependent on chemical properties and also the exposure dose. Exposure may occur through inhalation of contaminated air, accidental ingestion of contaminated food, soil or water, and through absorption by dermal contact. The different at-risk groups from population centers along the Straits of Mackinac were categorized based on susceptibilities to adverse effects from both acute and chronic exposures to chemicals of potential concern (CoPC) associated with the Line 5 petroleum products.

The CoPC released from a potential worst-case Line 5 pipeline rupture is predicted to enter the water, air, and soil of areas along the Straits of Mackinac within 24 hours of a spill event. The following conclusions were reached regarding the potential effects and increased risks that CoPC may pose to public health and safety under a worst-case spill event:

- Concentrations of CoPC such as VOCs proximate to the immediate release area will initially be very high ranging up to 5×10^4 milligrams VOCs per cubic meter of air (mg/m^3). However, as these VOCs become dispersed downwind, the concentrations of the individual constituents decrease with increasing distance from the release point.
- Reduced concentrations of CoPC reaching population areas due to downwind dispersal would minimize the risks to public health and safety associated with CoPC toxicity and flammability hazards under a worst-case release scenario.
- Seasonal residents were determined to be at higher levels of individual risk from CoPC exposure hazards relative to permanent residents. Although generally low, the increased level of risk for seasonal residents was associated with their higher potential for participation in recreational activities that can increase exposure rates.
- Acute exposures to CoPC may lead to immediate but transient adverse health effects ranging from general mild discomfort, sensory organ irritation, shortness of breath, headache and nausea. These effects, however, would not persist upon removal of human receptors to CoPC exposure or the source(s) of CoPC.
- It is unlikely that the public would be continuously exposed to concentrations of CoPC that are above acceptable risk levels for an extended period. This exposure unlikelihood is associated with the volatile nature of CoPC BTEX and their short half-lives in the air that reduce the risks of long-term exposure and adverse health effects.
- None of the individual CoPC constituents were predicted to exceed the upper target limit for cancer risk. However, estimated CoPC concentrations may result in some non-cancer related adverse health effects.
- Public water supply sources and private drinking water wells located around the study area would be at risk of oil contamination. However, the underground water flows towards the lake. Therefore the risk to residents is relatively low. Although, residents

collecting drinking water directly from surface water sources could be at a higher risk of developing health effects from the oil toxins.
- Direct and indirect impacts from the oil spill accidents could provoke mental stress, depression, and chronic post-traumatic stress disorders among residents especially women, children and the indigenous people of the community. Therefore mental health services may be required long after cleanup and recovery activities have been completed.
- The flammability and explosive hazards modeling showed minimal risks to the residents closest to the potential worst-case release point. Among the population groups, the model predicted 0% mortality. Therefore the risk to public health and safety from fire and explosion hazards are negligible.

The predicted risks to public health and safety risks reported in this study as associated with a Line 5 worst-case spill event in the Straits of Mackinac are relatively low with no potential fatalities or long-term adverse health effects anticipated. A limitation of this study is that these conclusions are only valid for the assumed conditions and the data available for the analyses. Using extant studies and validated regulatory guidelines and methods, the results of this study predict that any increases in the short- and long-term risks to public health and safety as associated with the release of crude oil or NGL products following a Line 5 pipeline would be low.

Task E: Analyzing the short and long-term ecological impacts.

An estimated 324-888 km of shoreline in Lake Michigan and 449-1075 km of shoreline in Lake Huron are at risk of oiling following a rupture in Line 5 pipeline, depending on the weather conditions at the time of the spill. Immediate toxicity from short- and long-term exposure to oil can induce detrimental physiological responses. Also, many species are vulnerable to habitat and trophic-level alterations arising from damage to habitat structure and prey communities. Therefore, both the physiological and ecological effects of oil on organisms can have long-term consequences for species numbers, fitness, and population recovery and persistence. Adult fish that live and feed in sediments that are contaminated with oil are also at risk; these include Lake Whitefish, an economically valuable species. Finally, declines in abundance of primary producers, such as phytoplankton, and primary consumers resulting from an oil spill would disrupt the food web and affect the broader ecosystem in oiled areas.

Ecological Profile and Vulnerabilities

The waters and shoreline areas of Lakes Michigan Huron including those surrounding and adjacent to the Mackinac Straits contain abundant natural resources that are of great ecological and economic value. A variety of habitats including nearshore and deepwater, beaches, wetlands, coastal dunes and forests support a variety of hallmark species that, together, comprise a rich and healthy Great Lakes ecosystem. In this regard, the purpose of Task E is to evaluate risks to this ecosystem from Line 5 rupture and subsequent oil spill in the Straits of Mackinac.

Crude oil contains over 2,000 individual compounds including chemicals include short-chain aliphatic hydrocarbons and BTEX that are very toxic but will be rapidly degraded and volatilized and polycyclic aromatic hydrocarbons (PAHs) that are very toxic and can represent a chronic hazard in the environment for much longer periods.

Our evaluation of risk to natural resources in and surrounding Mackinac Straits estimated that 324-888 km of shoreline in Lake Michigan and 449-1075 km of shoreline Lake Huron are at risk of oiling following a rupture in Line 5 pipeline. Nearly all this reach of shoreline would exceed thresholds of both NOAA's Socioeconomic Factor (SEF, 1 g/m^2) and Ecological Factor (EF, 100 g/m^2) and require clean-up and remediation (Figure ES9). The sediment PAH concentrations in many shoreline habitats could also exceed the Threshold Effect Concentration (TEC, 1,610 µg/kg) or the Probable Effect Concentration (PEC, 22,800 µg/kg) for PAH toxicity, depending on the PAH content of the released oil.

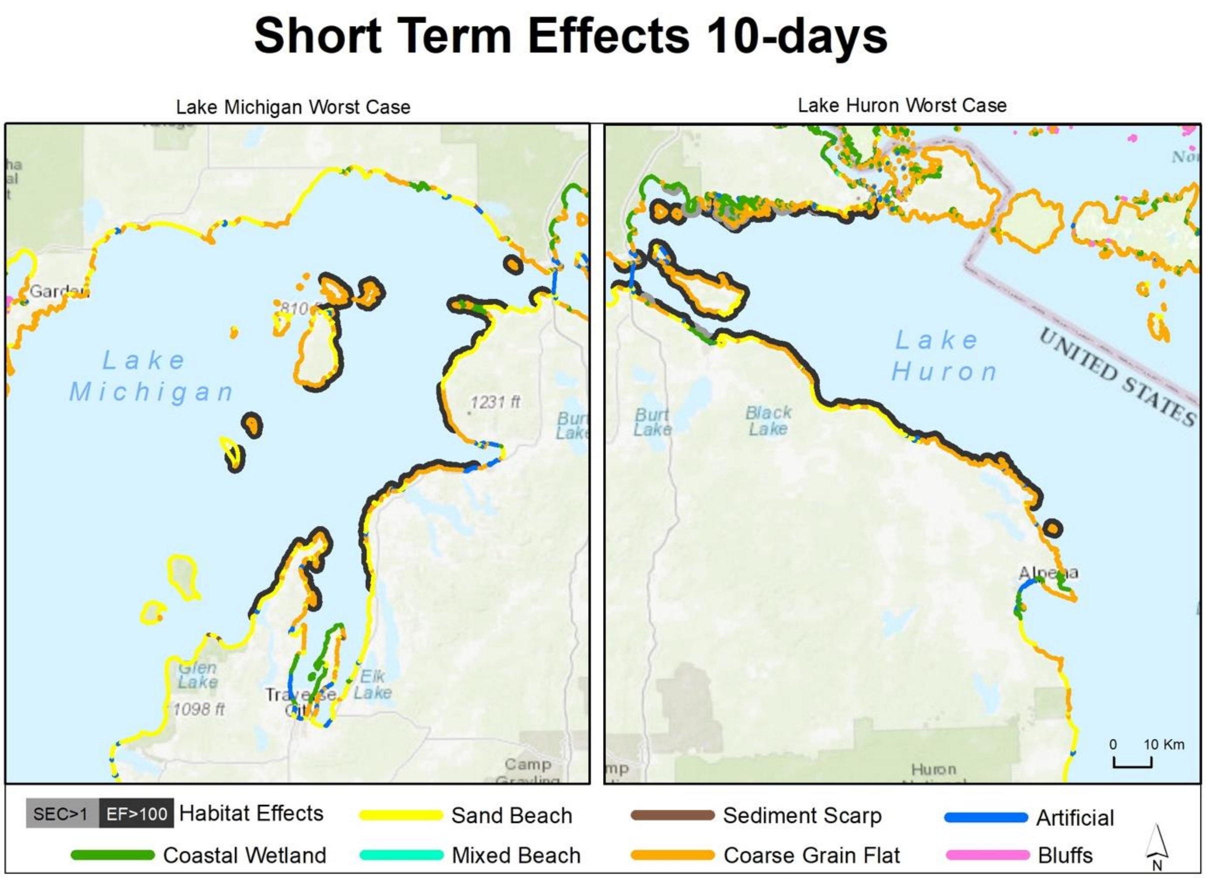

Figure ES9: Shoreline habitats exceeding thresholds for socioeconomic (SF >1g/m^2, light grey) or environmental (EF >100g/m2, black) impacts 10 days after a worst-case spill in either Lake Michigan, left) or Lake Huron (right).

Toxicity from short- and long-term exposure to oil can induce detrimental physiological responses. Also, many species are vulnerable to habitat and trophic-level alterations arising from damage to habitat structure and prey communities. Therefore, both the physiological and ecological effects of oil on organisms can have important consequences for species numbers, fitness, and population recovery and persistence.

The Great Lakes have faced a range of anthropogenic stressors and for native mammals, birds, fishes, reptiles, amphibians, micro-organisms, and plants. An oil spill would increase this stress, especially in nearshore habitats where spilled oil tends to accumulate following dispersal. A total of 47 state- and federally-listed species of conservation status have been identified in the areas surrounding Mackinac Straits. Additionally, approximately 60,000 acres of rare and unique habitats are at risk. Open dunes, wooded dune and swale, and marsh dominate these shoreline habitats. These areas are important habitat for insects, fish, waterfowl, waterbirds, and mammals. They serve as feeding areas for migrating and nesting shorebirds including Piping Plover and Tern species. Bird species are especially vulnerable to mortality and chronic health effects from oil exposure because they use open water, coastal and wetland areas adjacent to and surrounding the Mackinac straits during spring and fall bird migration. Fish species of ecological and economic importance are at risk from oiling of spawning grounds and nursery habitats, which would limit reproduction and reduce the population. Spawning locations that could be contaminated in the two scenarios examined are shown in Figure ES10. Adult fish that live and feed in sediments that are contaminated with oil are also at risk; these include Lake Whitefish, an economically valuable species. Finally, declines in abundance of primary producers, such as phytoplankton, and primary consumers resulting from an oil spill would disrupt the food web and affect the broader ecosystem in oiled areas.

The distinctive habitats and tightly coupled food webs in and around the Straits of Mackinac are linked to lake-wide distributions of fishes and hemisphere-wide migrations of birds. Thus, the consequences of an oil spill would reach far beyond the zone initially touched by oil.

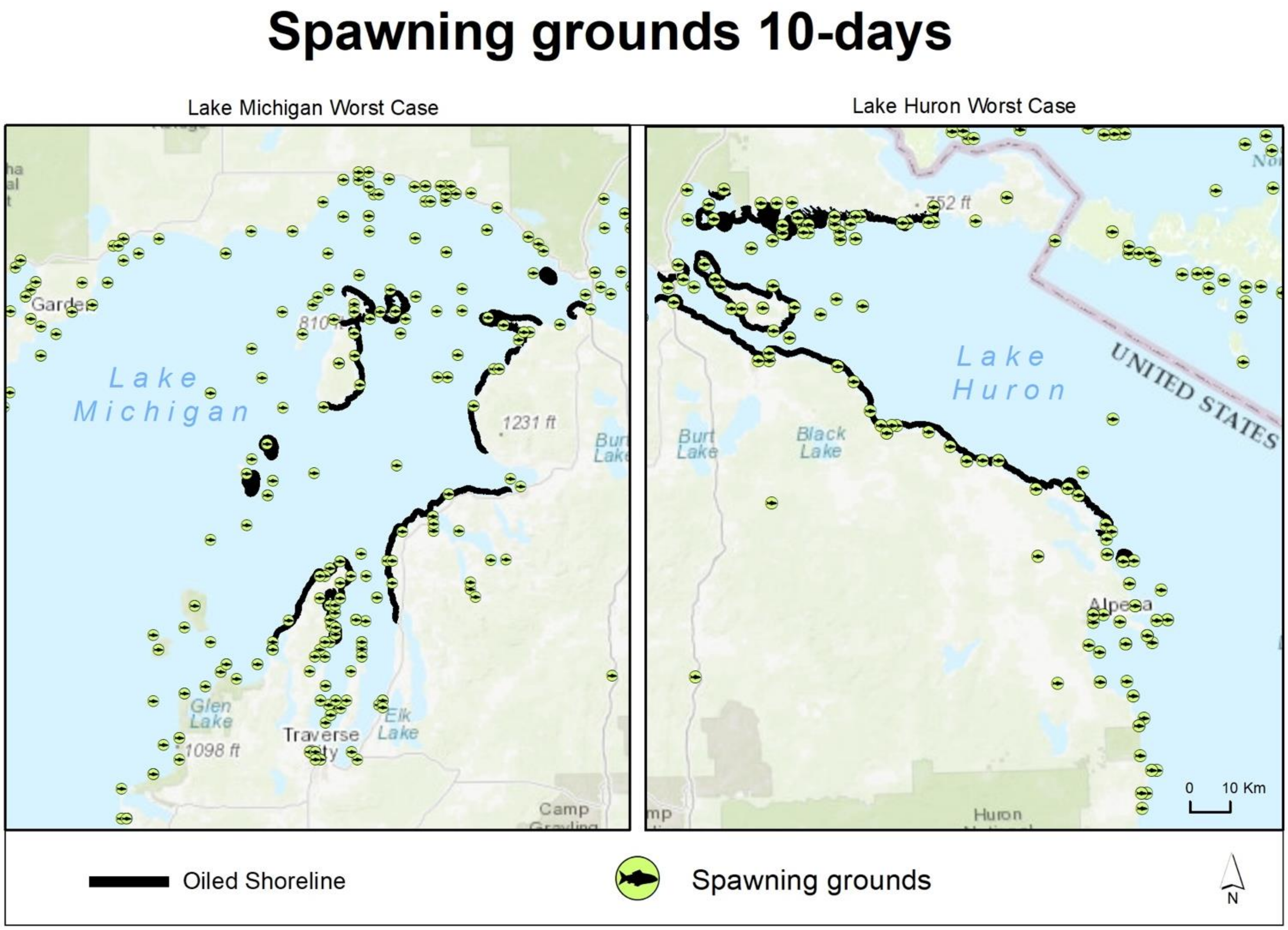

Figure ES10: Oiled shorelines and spawning sites of fishes in Lakes Huron and Michigan based on GLAHF and Goodyear Atlas.

Task F: Analyzing potential measures to restore the affected natural resources and mitigate the ecological impacts.

Focusing on the same set of ecological-worst-case scenarios that were analyzed for Task E from the perspective of restoration, a wide range of estimates for primary ecological restoration was identified based on analogous spills. These ranged from a low end of $165 million to $229 million (if cleanup costs per km are similar to those of the 2010 Marshall, MI spill) to a high end of $991 million to $1.327 billion (if cleanup costs per km are equivalent to those of the 2010 Deepwater Horizon spill). Due to their respective locations, response to a worst-case Straits spill would be more comparable to the Marshall spill response than the Deepwater Horizon spill in several ways, although there are important differences between the two in the product spilled and its fate. For the purpose of calculating the total costs of one specific scenario across all tasks, the Marshall cost basis was applied to the March scenario that was the focus for Tasks G, H and I (Table ES6). This spill scenario, representing unmitigated conditions, includes 996 km of oiled shoreline across both lakes, corresponding to a cleanup and restoration cost of approximately $500 million. Cultural resources cannot be restored to baseline; therefore their loss must be compensated through compensatory restoration.

Mitigation Context and Methods

The waters and shoreline areas of Lake Michigan and Lake Huron and the areas surrounding and adjacent to the Straits of Mackinac contain abundant and valuable natural and cultural resources. The Oil Pollution Act (OPA) mandates a Natural Resource Damage Assessment/Damage Assessment and Restoration Plan (NRDA/DARP), which is an evaluation of possible injuries to natural and cultural resources, and the development and implementation of a plan to restore those resources to their baseline. Restoration takes two forms: primary restoration is defined as actions taken to restore the environment to the condition that existed before the incident, and compensatory restoration is defined as actions taken to reimburse the public for losses that occurred between the incident and the restoration to baseline. The environment is broadly defined to include the natural habitat and cultural resources, which include archeological sites and unique landscapes. Task F focuses on primary ecological restoration. Compensatory restoration cannot be fully determined until baseline has been reestablished. Because cultural resources cannot be restored to baseline, their loss must be compensated through compensatory restoration.

The worst-case spill for Task F was chosen as the scenario that results in the greatest distance of coastline oiled. Restoration requires removal of oil (clean-up phase) and the rehabilitation of the environment following a worst-case oil spill. Removal of bulk oil from the physical habitat is generally accomplished through mechanical excavation, but in cases where the environment is especially fragile such as in wetlands, manual removal may be more appropriate. Any plants and sediment removed would need to be replaced with native plantings and clean sediment of a similar type. Fertilizer might be applied to stimulate the growth of vegetation, both terrestrial and aquatic. Bioremediation, perhaps coupled with biostimulation, may be suitable for the removal of residual oil. Bioremediation can be slow; thus, long-term monitoring would be essential to make sure that oil is being degraded.

The recovery of the affected fauna populations depends on the restoration of their habitat. Restocking of affected fauna (mollusks, bivalves, mammals, birds, fish, reptiles, etc.) could be needed. In all cases, reduction in human-animal interactions would be recommended, and the monitoring of indicator species would be critical to determine whether recovery was proceeding as desired. Damaged cultural resources may not be amenable to restoration. Therefore, for cultural resources, the goals would be to document damages and prevent further injuries during clean-up and restoration.

The proposed restoration strategies have been used as part of restoring oil spills in the past. Thus, there is a high likelihood of success applying these strategies in the Great Lakes. However, the exact restoration approach will need to be developed by the trustees during the NRDA process. As the professional best-practices shift to more collaborative management styles, in addition to the relevant branches of government, consideration should be given to the participation of stakeholders, such as citizen action groups, residents, and tribal entities in a collaborative management arrangement.

Estimates of the cost of primary ecological restoration of shorelines were determined from comparisons with the Enbridge Line 6B oil spill near Marshall, MI, and the Deepwater Horizon oil spill. The costs for those shoreline restorations were $0.51 million/km for Line 6B and $3.06 million/km for the Deepwater Horizon. The likely projected cost to restore from 324 km to 449 km of Great Lakes shoreline could range from $165 million (Marshall cost basis) to $1.372 Billion (Deepwater Horizon cost basis). As described above, application of the Marshall cost basis to the most costly scenario analyzed by Tasks G and I (Scenario 1, Table ES6) results in a total cost of approximately $500 million.

Task G: Estimating the amount of natural resource damages that would result from a worst-case release.
and
Task I: Estimating all other economic damages, public and private, that would result from a worst-case release.

In this report, we identify the potential economic damages and economic impacts associated with a worst-case spill at the Straits section of Enbridge's Line 5 for the State of Michigan. Under the OPA, any losses to the value of recreational uses of natural resources are part of the public claim against the spill's responsible party. In all scenarios examined, the largest single category of natural resource damage was lost recreational use values for beach visitation with a loss of just under $400 million. Overall, in the worst spill, recreation damages for all natural-resource-related recreation activities totaled approximately $460 million. We also quantified damages to drinking water for municipal intakes and groundwater wells, as well as several other categories of potential economic losses due to a spill that would likely be considered private claims under OPA, such as increased gas prices, lost enjoyment from coastal properties, decreased commercial fisheries harvest due to closures, and increased costs to commercial navigation. Adding these damages to the lost recreation values yields economic damages of $690 million in our worst-case scenario. Finally, we also measured changes in incomes to workers and owners of tourism-related businesses, and in our worst-case scenario, this lost income is $680 million. Thus, with caveats as noted in the methods and conclusions, for the impacts we were able to quantify, our estimated worst-case economic damages range from $450 million to $1.37 billion depending on the direction and spread of the spill. Among the spill simulations, we examined, the spill in which oil spreads westward along the northern Lower Peninsula shore of Lake Michigan and reaches Wisconsin caused the largest measured damages.

Task H: Estimating the governmental costs that would be incurred as a result of a worst-case release.

In the case of an oil spill in the Straits, federal, state, provincial, municipal, First Nation, and Tribal governments and their respective agencies will coordinate their responses, each employing different policy mixes. Task H of this analysis was to estimate the total governmental costs that would be incurred as a result of the release. Using the government costs associated with the Marshall, Deepwater Horizon, and Exxon Valdez (adjusted for inflation) oil spills, estimates for equivalent costs for a worst-case Straits spill generated based on spill volume were $127 million; estimates based on shoreline miles oiled ranged from $123 to $535 million depending on weather conditions. These costs would be reimbursable by Enbridge as the responsible party.

The analysis team for Task H also estimated additional government costs that would likely not be reimbursable using key results from the Task I investigation of the regional economic impacts of a worst-case oil spill from Line 5 in the Straits of Mackinac. Tax revenue reductions related to reduced visits by out-of-state tourists and the resulting decline in direct economic activity to those affected businesses were estimated at up to $24.3M for Michigan, $38.7M for Wisconsin, and $112.4M for the federal government. This includes taxes on sales and lodging not collected by the States of Michigan and Wisconsin from the lost economic activities, lost state and federal tax revenues from transportation fuels not sold due to an oil spill, and lost income taxes for Michigan, Wisconsin, and the federal government. Gains in state and federal tax revenues because the expenses paid by responsible parties for responding to and cleaning up an oil spill would increase household incomes above the level before the oil spill was also estimated based on a total cleanup cost of $500M, which was extrapolated from the total cleanup cost of the Marshall spill. These gains were estimated at $21.3M for Michigan and $110M for the federal government, for total impacts on tax revenue of -$3M for Michigan, -$38.7M for Wisconsin, and -$2.4M for the federal government. Finally, lost government tax revenue from the application of the cleanup cost deduction and government reimbursement as a business expense was estimated at $262.5M based on the typical ratio of cleanup costs to total spill costs.

Task X: Broader impacts.

To provide a balanced assessment of the Straits Pipeline, Task X pursued two overarching objectives. First, the team aimed to provide an overview of perceived risks arising out of a potential oil and petroleum product release from the Straits Pipelines (“petroleum release”). Second, the team engaged with concerns over a potential petroleum release expressed by local communities, civil society groups, indigenous communities, government actors, and the public at large. The primary data source was the public comments on Dynamic Risk's 2017 Alternatives Analysis draft and final reports because this was the largest and most easily accessible data source available documenting the attitudes these actors currently hold toward the Straits Pipelines. To understand Tribal concerns the regarding the “worst-case scenario” in the event of a petroleum release from the Straits Pipelines, we conducted a discourse analysis of correspondence between Michigan's Tribal communities and the Michigan Petroleum Pipeline Task Force. Also, we sent letters to the aforementioned Tribal Nations asking for their inputs within the scope of Task X Statement of Work. In these letters, we sought feedback from Tribal leaders regarding how they would define a worst-case event and how a worst-case oil spill would affect their community, their environment, and their lifeways.

Public comments demonstrate the importance of maintaining clean lake waters for the economic and cultural value they provide for all residents of Michigan, including Tribal community members. The provisioning of lake water ecosystems is viewed as essential for businesses, tourism, and cultural identity in the state. Impacts to water quality are viewed as the largest perceived risk of continued operation of the Straits Pipeline, but the impacts are perceived as expanding beyond clean water to impact the potential to maintain a robust economy and flourishing communities throughout the state.

In an analysis of public comments, only organizations that benefit economically from continued operation express support (and most do not comment on the Alternatives Analysis itself, but rather offer a generic expression of support). The concept of a social license to operate (SLO) provides context for interpreting this and other findings in this report. SLO is pursued by industrial actors and is often associated with those responsible for ensuring the safety of industrial activity. However, industrial actors cannot themselves grant SLO, which must come from the community stakeholders potentially impacted by the industrial activity. In the case of this analysis, SLO appears to be lacking, as most comments focus on the relative risks outweighing benefits, which are viewed as disproportionately distributed to actors who do not themselves bear any of the associated risks. This analysis suggests that withdrawal of SLO is based on lack of public trust in the process of evaluating the safety of industry activity associated with continued operation of the aging infrastructure of the Straits Pipeline.

Michigan's Tribal Nations share a collective concern over the existence and continued use of Enbridge's Line 5 pipeline. Tribal Nations view certain resources as irreplaceable, and their loss as a complete ruin, which makes it difficult to apply conventional damage valuation procedures. The correspondence between Tribal Nations and the State of Michigan provided information about how Tribal communities would be affected by the continued use of the Straits Pipelines, including potential damage to the Tribal fishing industry along with the economic impacts of a declining Lake Michigan tourist industry. In follow-up correspondence with the task team, Tribal Nations also voiced concerns regarding risks to traditional lifeways such as the identification of culturally significant plants as well as the practice of harvesting, cooking and consuming, traditions and knowledge that have been passed down from generation to generation. A Straits spill could also damage traditional cultural properties, cemeteries, and sacred sites. Tribal representatives informed us that in the event of an oil spill in the Great Lakes, they "will explore all legal avenues for relief."

Summary of Costs and Next Steps

One objective of this Independent Risk Analysis was to estimate the total potential liability from a worst-case scenario spill. The 1953 Easement "makes Enbridge liable for all damages or losses to public or private property" (Risk Analysis Final RFP 2017). To sum all damages across tasks based on the scope of work for this assessment, it is necessary to assume a single scenario. Of the three scenarios used as case studies by the Tasks G/I and Task H teams, their "Scenario 1", based on an unmitigated release of 58,000 bbl caused by a double rupture of the Straits Pipelines at the bottom of the shipping channel during the current and weather conditions experienced on March 1, 2016, resulted in the highest damages and is summarized here.

The total cost, broken down into broad categories, is presented in Table ES8 below. Enbridge's liability would include the reimbursable government costs estimated by Task H, which are a component of the $500 million in estimated total cleanup costs. Further details, including ranges for many of these values, are available in Tasks F, G/I, and H, as noted. Task H also estimated non-reimbursable costs to government, including an approx. $42 million net loss in Michigan/Wisconsin state tax revenues, a $2 million net loss in federal income tax revenues, and $263 million in lost corporate income tax revenue due to a tax deduction of cleanup costs, which are not included in the total liability estimate.

Table ES8. Summary of total potential liability for a worst-case spill from the Straits Pipelines.

Liability	Task	Estimate (millions)
Cleanup costs	F, H	$500
Recreational damages	G/I	$460
Lost income for tourism and recreation businesses	G/I	$678
Other damages	G/I	$230
Total		$1,868

This cost estimate was made as comprehensive as possible but does not include the cost of repairing the pipeline itself or the costs of irreversible damage to resources for which valuation estimates are not available. Comparison to other estimates of the costs of a Straits Pipeline spill should be made with caution, taking into account differences in assumptions and varying included costs.

The public release of this report will be followed by a 30-day public comment period. During this comment period, the analysis team will prepare and present a public information presentation summarizing the draft analysis. This presentation is currently scheduled for August 13 in Gaylord, MI. The team will then consider and respond to comments on the draft report, making any appropriate revisions to the analysis, and deliver a final version of the Independent

Risk Analysis to the State by September 15, 2018. The revisions made to the final report may result in changes to the numbers summarized above as well as throughout the report.

References

Michigan Petroleum Pipeline Task Force Report of July 2015, https://mipetroleumpipelines.com/document/michigan-petroleum-pipeline-task-force-report

Risk Analysis RFP https://mipetroleumpipelines.com/documents?tid=All&keys=Risk+analysis+RFP

Chen, C., Beardsley, R.C., Cowles, G. (2006). An unstructured grid, finite-volume coastal ocean model (FVCOM) system. Oceanography 19, 78–89pp.

Dynamic Risk Assessment Systems, Inc. (2017). Alternatives Analysis for the Straits Pipelines – Final Report, p. PR-4. Document number SOM-2017-01-RPT-001. Retrieved from https://mipetroleumpipelines.com/document/alternatives-analysis-straits-pipeline-final-report

Fidler, J., and Wennersten, R. (2007). What is a worst case scenario for a potential accident and how can it be used? InIChemE SYMPOSIUM SERIES (No. 153).

Schwab, DJ. (2014). Straits of Mackinac Contaminant Release Scenarios: Flow Visualization and Tracer Simulations. U-M Water Center Research Report, 7pp. Available from http://graham.umich.edu/water/news/mackinac-straits-contaminant-scenarios

Schwab, DJ. (2016). Statistical analysis of Straits of Mackinac Line 5: Worst case spill scenarios, 23 pp. http://graham.umich.edu/water/project/mackinac-oil-spill

Venosa, A. D., Zhu, X. (2003). Biodegradation of crude oil contaminating marine shorelines and freshwater wetlands. Spill Science & Technology Bulletin, 8(2), 163-178.

CFR (2018) Title 33: CFR Appendix C to Part 154, Guidelines for Determining and Evaluating Required Response Resources for Facility Response Plans.

Project Team and Roles

Table ES9. Risk analysis project team members and roles.

SECTION	TASK	LEAD	SCIENTIST	AUTHOR(S)	OTHER(S)
A	Worst Case	Amanda Grimm (MTU)	Ying Huang (NDSU)	Guy Meadows (MTU)	
				Mir Sadri-Sabet (MTU)	
				Samuel Ariaratnam (Ariaratnam Enterprise, Inc.)	
B	Fate & Transport	Gord Paterson (MTU)	Pengfei Xue (MTU)	Dave Schwab (UM)	Eric Anderson (NOAA)
				David Shonnard (MTU)	Philip Chu (NOAA)
C	Clean-up	Daisuke Minakata (MTU)	Aline Cotel (UM)	Amlan Mukherjee (MTU)	
				Stephen Techtmann (MTU)	
D	Public Health	Kelly Kamm (MTU)	Richard Olawoyin (OU)	Charles Ide (WMU)	
				Gord Paterson (MTU)	
E	Ecological Impacts	Jill Olin (MTU)	Charles Ide (WMU)	Marla Fisher (WMU)	
				Robert Powell (PASS)	
				Kevin Stryker (GVSU)	
				David Flaspohler (MTU)	
F	Restoration	Steve Techtmann (MTU)	Avery Demond (UM)	Aline Cotel (UM)	
				Timothy Scarlett (MTU)	
				Jill Olin (MTU)	
G	Nat Res Damage	Latika Gupta (MTU)	Frank Lupi (MSU)	Yongli Zhang (WSU)	
				Carson Reeling (WMU)	
				Max Melstrom (LUC)	
				Steve Miller (MSU)	
H	Gov Costs	Adam Wellstead (MTU)	John Bratton (LimnoTech)	David Shonnard (MTU)	
				Amlan Mukherjee (MTU)	
I	Public & Private Costs	Latika Gupta (MTU)	Frank Lupi (MSU)	Yongli Zhang (WSU)	
				Carson Reeling (WMU)	
				Max Melstrom (LUC)	
				Steve Miller (MSU)	
J	Final Report	Amanda Grimm (MTU)	Guy Meadows (MTU)	Sarah Green (MTU)	
SECTION	**TASK**	**LEAD**	**RESOURCE TEAM**		**DESCRIPTION**
X	Broader Impacts	Roman Sidortsov (MTU)	Alice Lipert (former DoE)	John Baeten (MTU)	Public Engagement, Qualitiative Considerations, and Native Community Interests
			Joanne Shore (former AFPM)	Chelsea Schelly (MTU)	
				Mark Rouleau (MTU)	

University of Michigan (UM), Michigan State University (MSU), Western Michigan University (WMU), Michigan Technological University (MTU), Oakland University (OU), Grand Valley State University (GVSU), Wayne State University (WSU), North Dakota State University (NDSU), Loyola University Chicago (LUC), Powell and Associates Science Services (PASS), Department of Energy (DoE), American Fuel & Petrochemical Manufacturers (AFPM)